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DELIVERABLES 1 & 2

MV LADY D INTACT STABILITY WITH WIND

Purchase Order No. NTSBF060005

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Prepared for:

National Transportation Safety Board
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Prepared by:

Alion Science and Technology
JJMA Maritime Sector
4300 King Street, Suite 400
Alexandria, VA 22302

1. INTRODUCTION

This report presents the results of Task 1 and Task 2 of NTSB Purchase Order NTSBF060005. It combines Deliverables 1 and 2 into a single report since the two tasks are very closely related. This report summarizes the basics of intact stability as they apply to pontoon vessels. It also describes the static intact stability of the MV LADY D that was analyzed for three loading cases and three wind speeds.

2. ASSESSING INTACT STABILITY OF VESSELS

Intact stability is the naval architect's term that describes how a vessel that is intact, or undamaged, responds when heeled (tipped) over. How a vessel responds when it is damaged is called damaged stability and that subject is outside the scope of this report. There are a number of forces that act on vessels that can cause the vessel to heel over. Some of the common heeling forces are: wind, waves, and the movement of passengers or cargo. Heeling forces are counteracted by the buoyancy of the hull of the vessel. As a vessel is heeled over the location of the buoyant forces shifts which produces a righting moment. If the righting moment is equal to the heeling moment, the vessel is in equilibrium and will remain in that position until the equilibrium is disturbed. If the heeling moment is greater the righting moment the vessel will continue to heel over and will turn completely over, or capsize.

The shape of the vessel's hull determines its buoyancy and how much righting energy is produced. In the case of a pontoon boat, see Figure 1, the two pontoons both produce buoyancy that counteracts heeling forces. The force of buoyancy of the two hulls can be turned into a single, (combined) buoyancy force. The distance measured perpendicular to the line of the combined buoyancy and the line of the weight of the boat is the "righting arm" of the boat. The greater the righting arm of the vessel, the more heeling force the vessel can resist.

Righting arm changes as a vessel is heeled over. When a vessel is floating level, with a heel angle of 0 degrees, the righting arm is zero because the force of buoyancy and weight are aligned. As a vessel is heeled over the center of buoyancy shifts outboard, creating a "righting arm" that tends to push the boat back to the upright position. As the vessel heels over further, the righting arm increases, see Figure 2, until it reaches a maximum. This point is called the vessel's maximum righting arm. Beyond the point of maximum righting arm, the righting arm decreases until it reaches zero, which is called the point of

vanishing stability. The distance from 0 degrees heel and the point of vanishing stability is called the vessel's "range of stability". At heel angles beyond the point of vanishing stability the vessel's center of gravity has shifted further outboard than the center of buoyancy and so the righting arm becomes negative, creating a moment that forces the vessel to heel more, eventually leading to capsize.

The area under the righting arm curve is a measure of the vessel's righting energy. The righting energy is important because this is the energy that is available to counteract forces that would heel the vessel over. This righting energy resists environmental forces that affect the vessel such as wind and waves. The vessel must have sufficient righting energy to counteract the environmental forces that the vessel is expected to encounter during its lifetime.
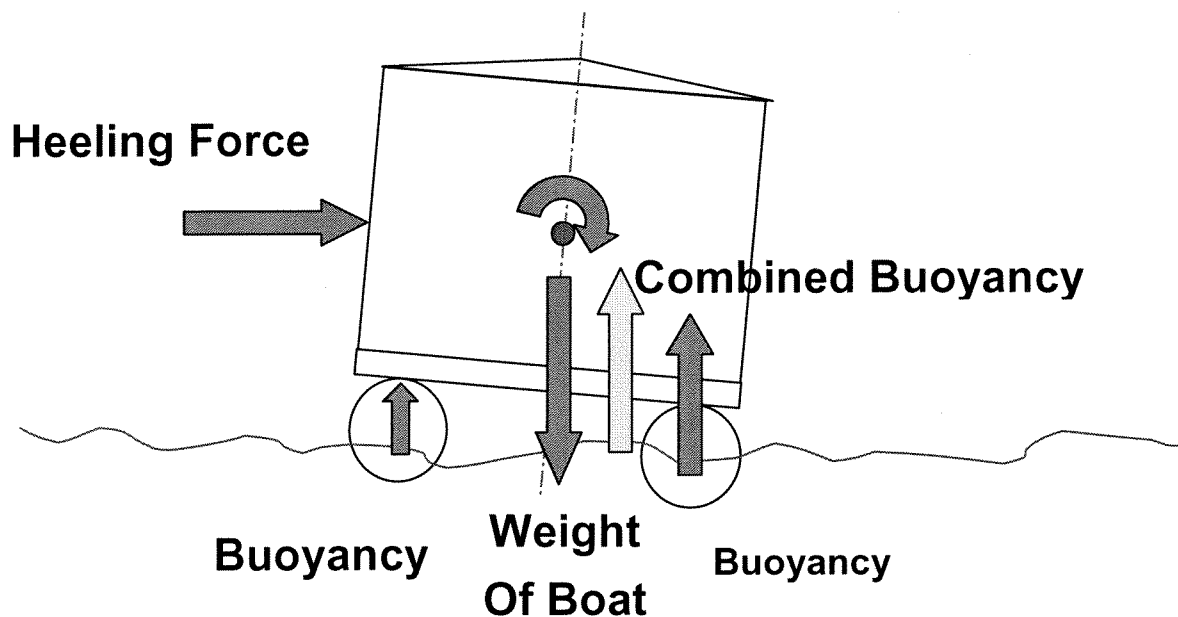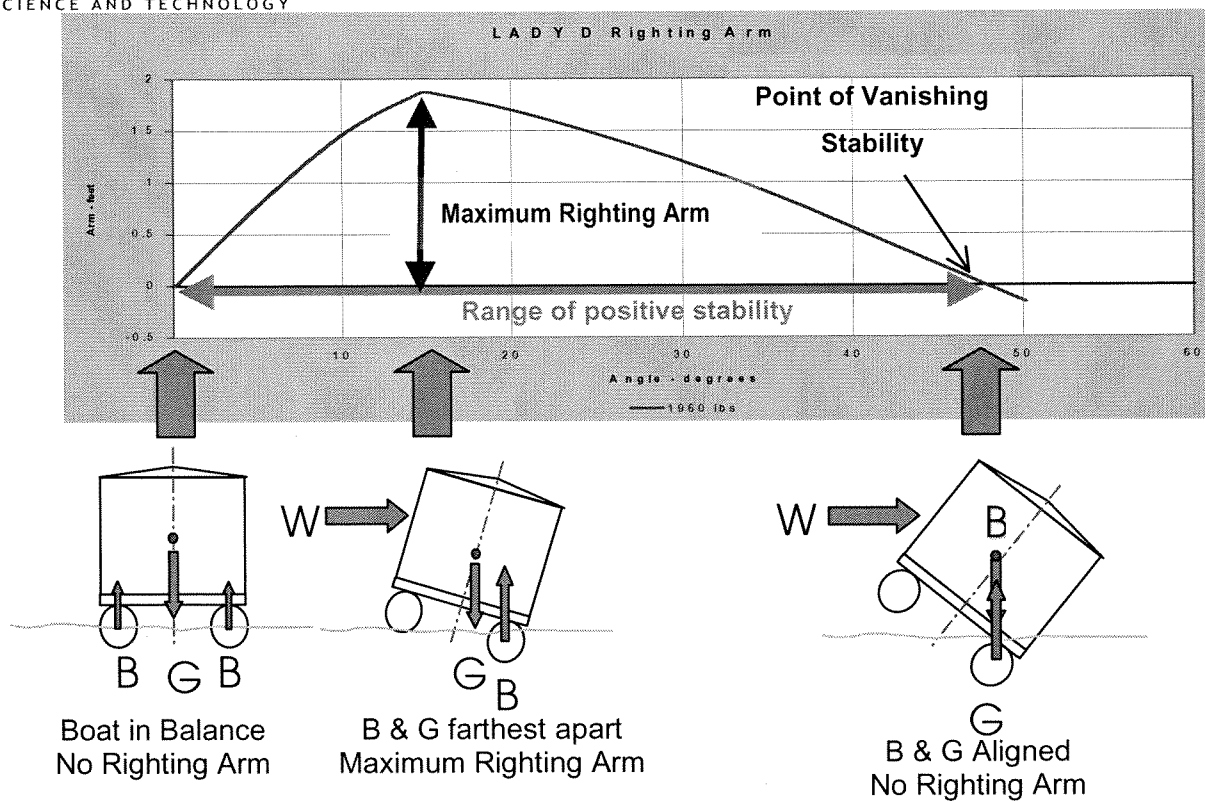

Heeling Force

Combined Buoyancy

Buoyancy

Weight Of Boat

Buoyancy

Figure 1 Intact Stability of a Pontoon Boat

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Figure 2 Righting Arm over a Range of Heeling Angles

The calculation of righting arm for any vessel is usually performed using computer programs. The hull form of the vessel is entered into the program for use in calculating a number of different properties of the vessel. These properties are referred to as the vessel's "hydrostatics". To calculate righting arm for the vessel, the program systematically changes the angle of heel of the hull. As the vessel is heeled, the program calculates the shift in the hull's center of buoyancy. The program adjusts the mean of the draft of the hull to keep the volume of water displaced by the hull (buoyancy) equal to the vessel's weight. Once the position of the hull's center of buoyancy (B) is calculated, the perpendicular distance from the vessel's center of gravity (G) to a line extending vertically from the center of buoyancy is measured. This is the vessel's righting arm, which naval architects refer to as GZ (see Figure 3). The intersection of the vertical line from the center of buoyancy (B) to the vessel's center line is called the ship's metacenter (M). The distance from the ship's center of gravity (G) to the metacenter (M) is referred to by naval architects as the vessel's metacentric height, also known as GM.
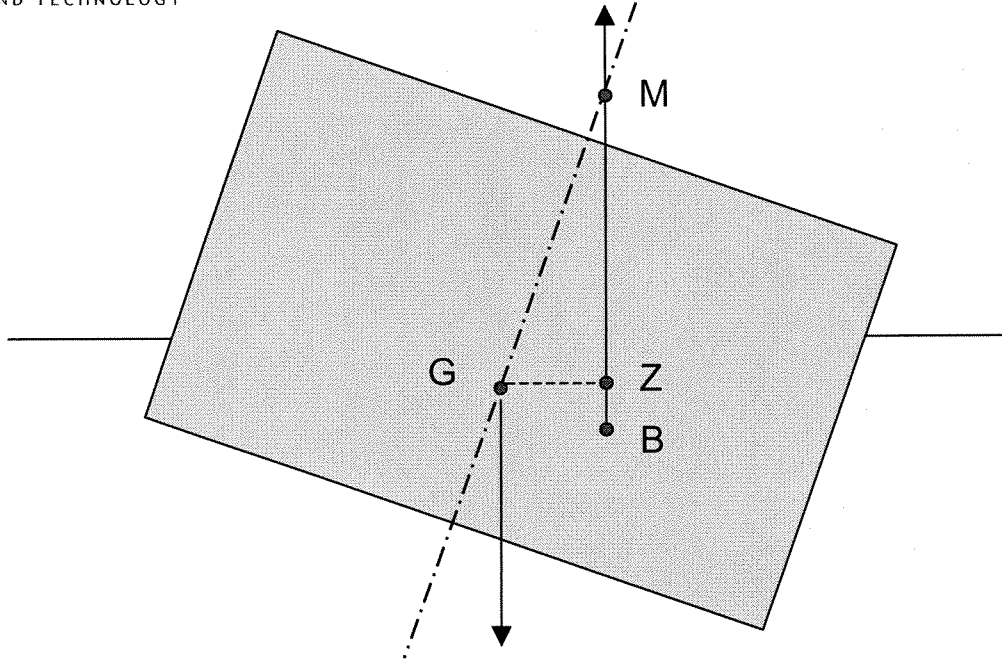
Figure 3 Calculation of Righting Arm

A vessel's GM is frequently used by naval architects as a measure of a vessel's stability. It is a good indication of the vessel's stability at small angles of heel ("initial stability"). The vessel's initial GM is the slope of the righting arm curve at zero degrees of heel angle (Figure 4). If the initial GM is high, the righting arm curve increases rapidly giving large righting arms for only small angles of heel. If initial GM is low, then the righting arm curve goes up slowly allowing the vessel to heel over farther. Vessels with positive GM when they are heeled to one side will resist the force and return themselves to a central upright position when the heeling force is removed. A vessel with negative GM is unstable and any upsetting force will cause the vessel to move away from its initial position. Vessels with two hulls, also called catamarans, such as a pontoon vessel, tend to have a very high initial GM, unless their center of gravity is very high or they are very heavily loaded.
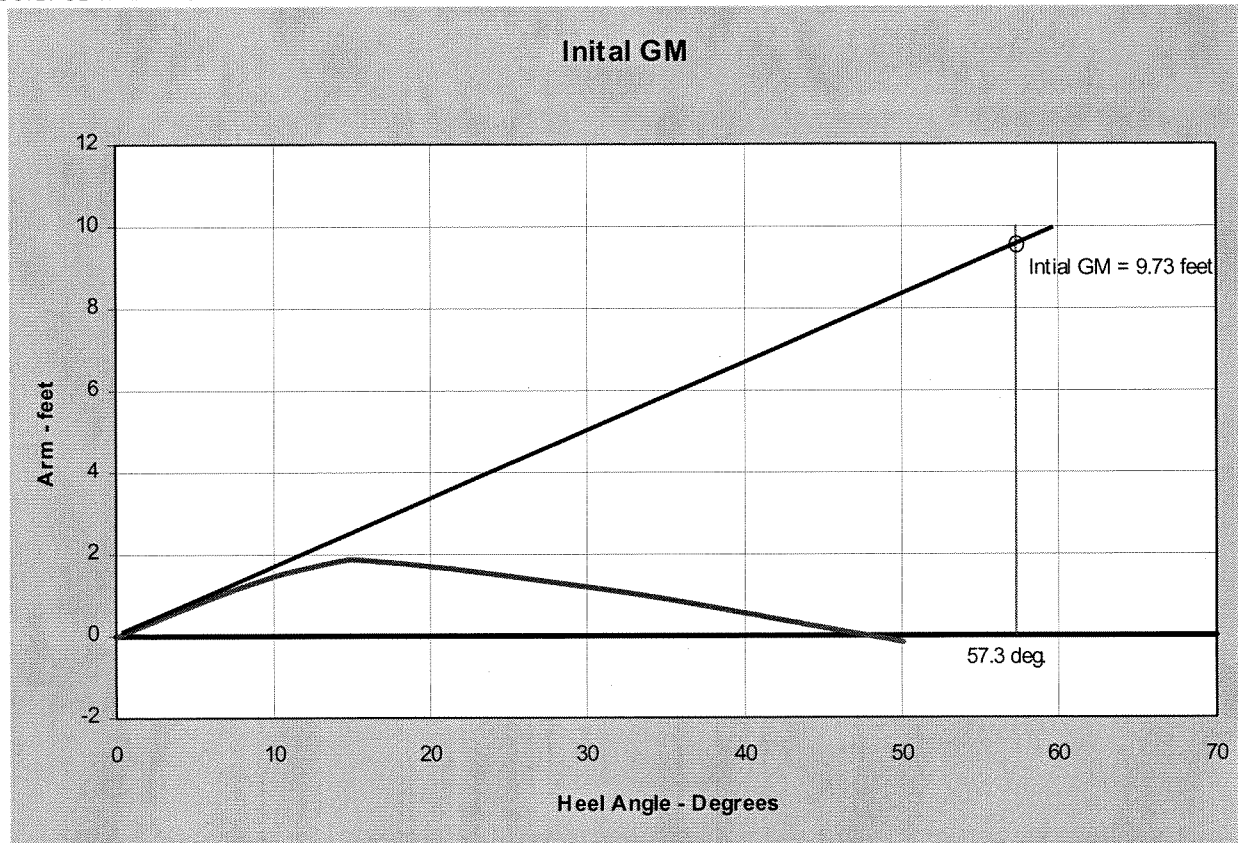
Figure 4 Initial GM

3. WIND HEELING FORCES

As mentioned in the last section, there are a number of common heeling forces that act on vessels: wind, waves, and passenger/cargo loads. Wind forces can be a major influence on any vessel. The major factors in calculating these forces are the area of the vessel that is exposed to the wind, also called sail area, and the wind speed. As a vessel heels over the sail area decreases so the heeling forces decrease. A sample graph showing wind heeling forces versus heeling angle is shown in Figure 5.
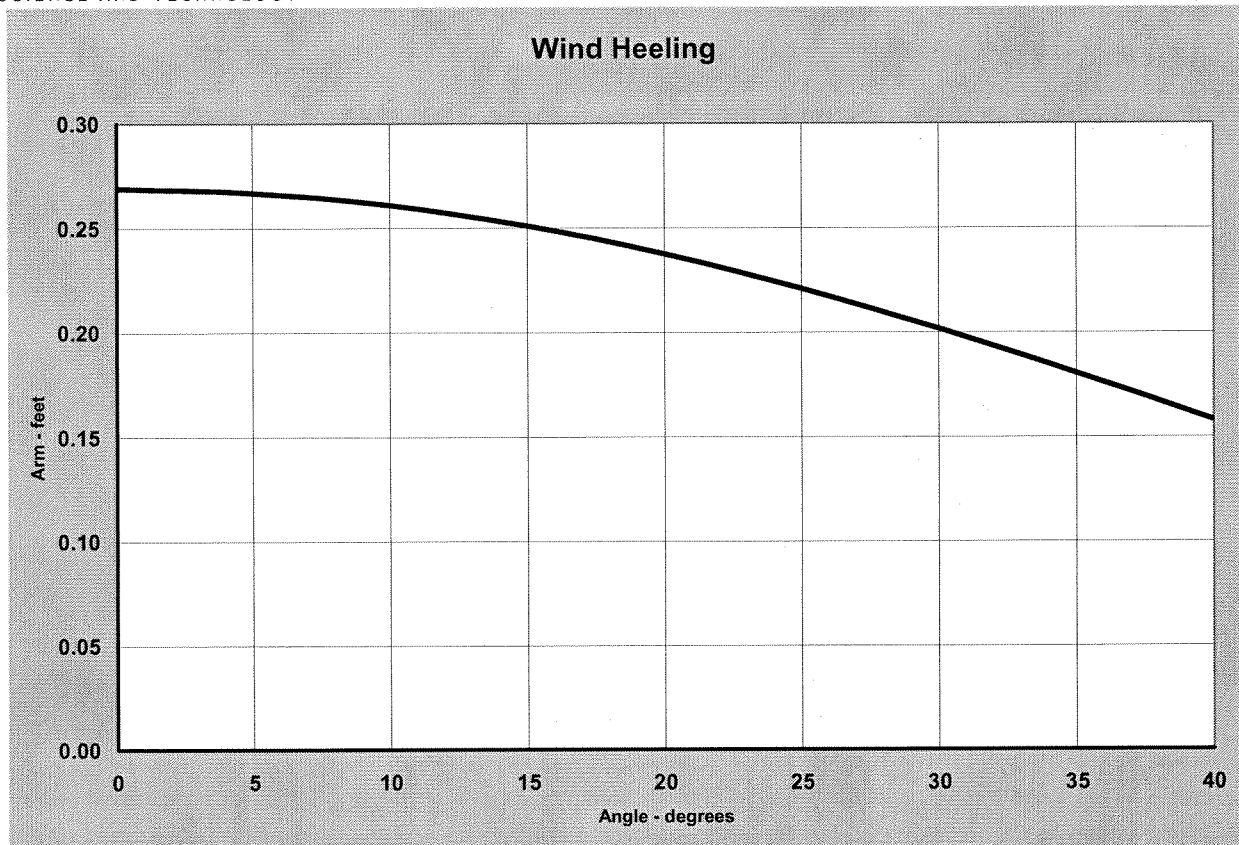
Wind Heeling

Figure 5 Winding Heeling Forces versus Heel Angle

Wind heeling arm curves are usually plotted on the same graph as a vessel's righting arm curve (Figure 6). The righting arm and wind heeling curves show important information about a vessel's intact stability in wind. The first intersection between the righting arm curve and the wind heeling arm curve is the equilibrium point. The angle of this intersection is how far the vessel would be heeled by a steady wind. If the wind heeling arm exceeds the vessel's righting arm the vessel will capsize. The second intersection point between the two curves is the point of vanishing stability in for the vessel at that wind speed. A steady wind heels a vessel over and reduces the amount of righting energy that is available to counteract environmental variables such as wind gusts or waves. The area between the two curves is called by naval architects the vessel's "residual righting energy". It is the vessel's reserve of righting energy that is available to counteract dynamic heeling forces. Stability criteria for ships that use the concept of righting energy usually do not consider the full area under the righting arm curve, but rather use only a portion of it, such as the area to the angle of maximum righting arm, the angle of downflooding, or a specified angle in degrees. This approach is conservative because it builds in an unspecified

factor of safety. The simplified stability test of 46 CFR 178.349 (PSST), does not explicitly require the calculation of wind heeling forces, but environmental factors are implicitly taken into account as part of the criteria used in the test.
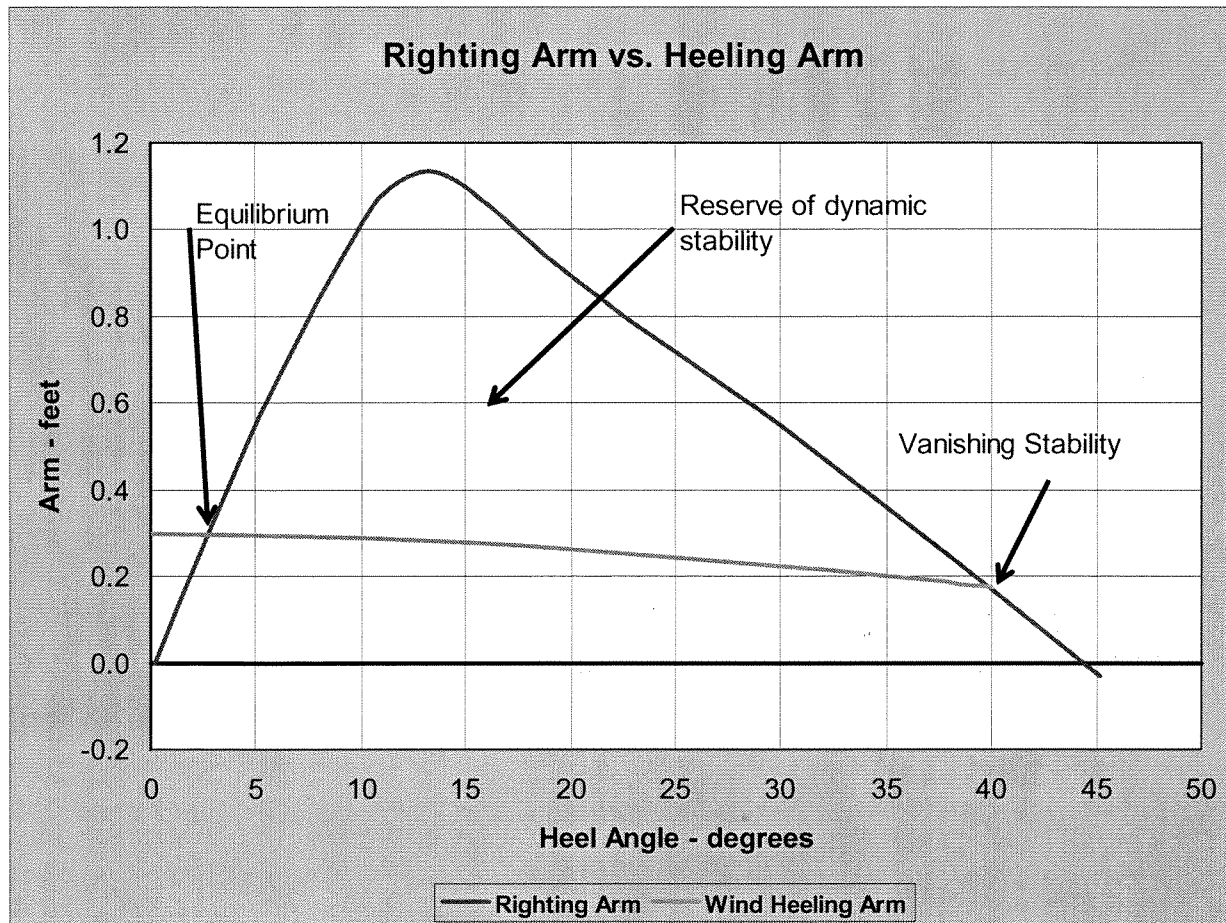
Righting Arm vs. Heeling Arm

Equilibrium Point

Reserve of dynamic stability

Vanishing Stability

Arm - feet

Heel Angle - degrees

Righting Arm   Wind Heeling Arm

Figure 6 Righting Arm versus Wind Heeling Arm

4. INTACT STABILITY OF THE MV LADY D IN 3 LOADING CONDITIONS

The weight of the passengers carried by the MV LADY D has a significant effect on the vessel's intact stability. Three load cases were examined which varied by the number of people on the vessel and their average weight. The first case examined was for 14 persons weighing an average of 140 pounds each (1960 pounds total). This case represents the maximum safe load condition allowed for the MV LADY D in accordance with the simplified stability test in 46 CFR 178.340. The second load case examined was for 25 persons each weighing 140 pounds (3500 pounds total). This case represents the load that

was allowed under the USCG Certificate of Inspection for the LADY D. The third loading case is the vessel loaded with 25 persons weighing an average of 168.4 pounds (4210 pounds total). This case represents how the LADY D was actually loaded at the time of the accident. For each of these three load cases curves of righting arm versus heel angle were developed. All three curves are shown plotted on one graph in Figure 7. The top, solid curve is for the first loading case of 1960 pounds. The middle, line with two dashes curve is for the second case with 3500 pound load. The bottom, dashed curve, is for the LADY D as loaded on the day of the accident (4120 pounds).
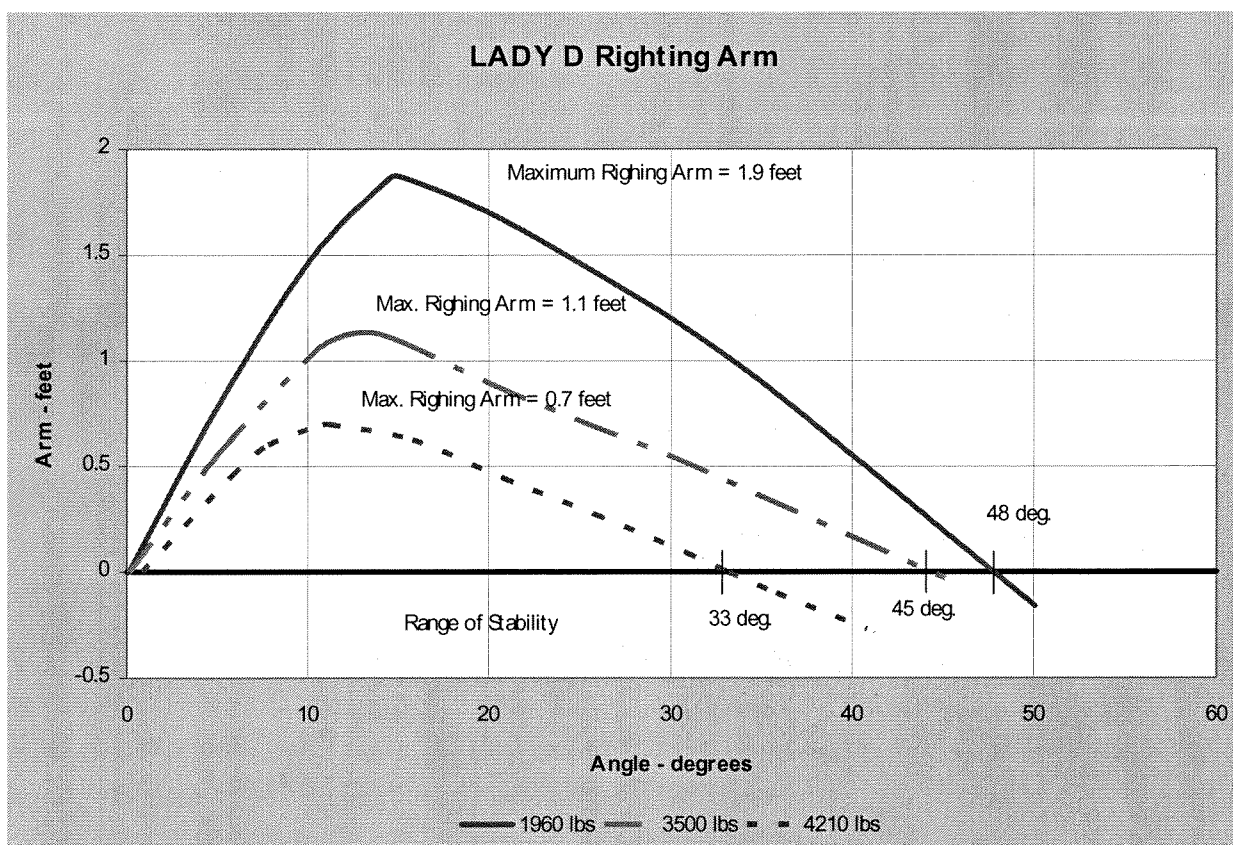
Figure 7 Righting Arm Curves for Three Load Cases

This figure shows how increasing the load carried by the vessel significantly decreases the maximum righting arm of the vessel and the range of stability. The maximum righting arm for the vessel in the first load case is 1.9 feet and it has a range of stability of about 48 degrees. In the second load case the maximum righting arm is 1.1 feet and the range of stability is about 45 degrees. In the third load case the maximum righting arm is only 0.7 feet and the vessel has a range of stability of only 33 degrees. On the day of the accident, once the LADY D reached a 33 degree angle of heel, there was no righting arm left to

bring the vessel back to an even keel so she would keep tipping until she was completely turned over.

The passenger load on the LADY D on the day of the accident had a major negative effect on the vessel's intact stability. The weight of the persons onboard the vessel increased her draft which reduced the reserve buoyancy of the pontoons. The reserve buoyancy of the pontoons, especially of the far side pontoon, is what produces the righting force that counteracts environmental forces that may heel the vessel farther over. Therefore the loss of the reserve buoyancy reduced the ability of the LADY D to resist environmental factors, such as wind and waves, on the day of the accident.

5. WIND HEELING FORCES ON THE DAY OF THE ACCIDENT

The ability of the LADY D, as loaded on the day of the accident, to resist wind heeling forces was examined for three wind speeds acting on the vessel's beam. The three wind speeds examined were 30, 40, and 50 knots. Wind heeling curves were generated for each of these wind speeds and they were plotted against the vessel's righting arm, as shown in Figure 8. The figure shows that as the wind speed increases the vessel losses "residual righting energy". In the 50-knot wind case, the wind heeling arm exceeds the vessels righting arm which would result in the vessel's capsizing. A steady state wind speed of 40-knots alone is not sufficient to capsize the vessel outright, but there is little "residual righting energy" remaining to counteract any other dynamic heeling forces such as wind gusts and waves.

Actual Loading Condition
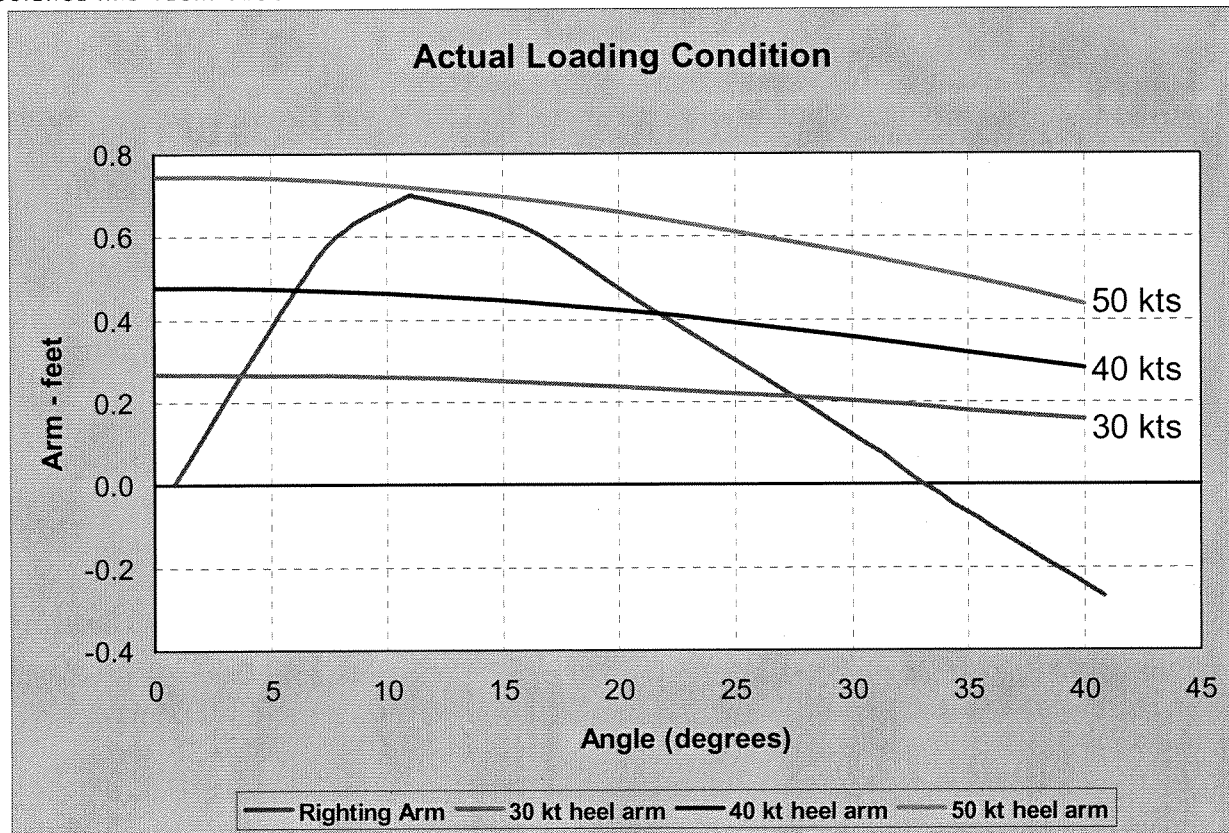
Figure 8 Righting Arm versus Wind Heeling Arm for 3 Wind Speeds

The impact of a 40-knot steady wind on the intact stability of the LADY D as loaded on the day of the accident is shown in Figure 9. This figure shows the "residual righting arm" for the vessel, which is the difference between the righting arm for the vessel and the wind heeling arm. The figure shows that a steady 40-knot wind would heel the vessel over to a 6.1 degree angle in calm water. Figure 10 is a sketch of the vessel looking at the bow in the heeled condition. The pontoon on the opposite side from the wind is deeply submerged and has little reserve buoyancy left to counteract any additional heeling forces. At an angle of slightly less than 22 degrees of heel, the vessel has no more righting energy and there is nothing to prevent the vessel from capsizing. Any additional external force (such as a gust of wind or a wave hitting the boat), a rapid maneuver by the boat's captain, or a shift in the boat's center of gravity due to passenger movements would be enough to capsize the vessel. At this wind speed there is very little margin remaining in the vessel's intact stability to counteract any additional heeling forces.
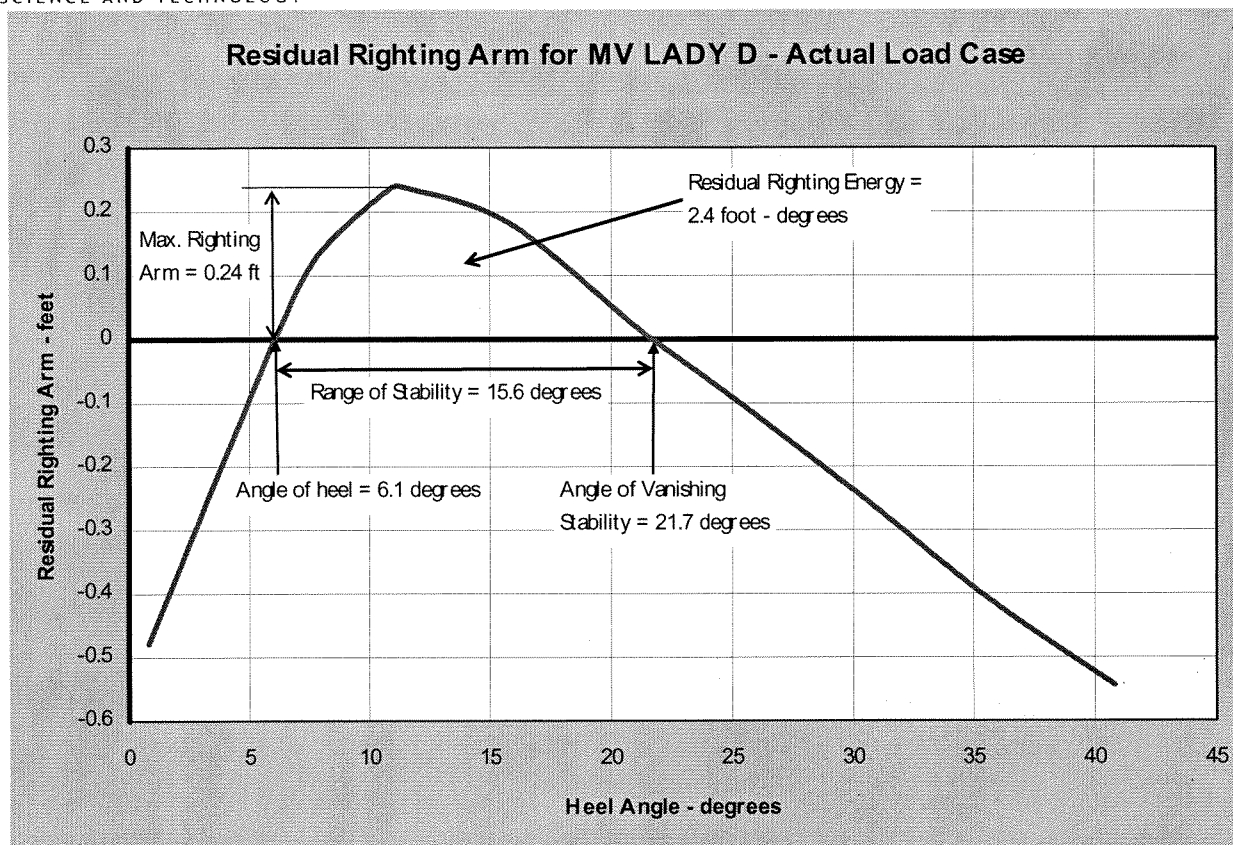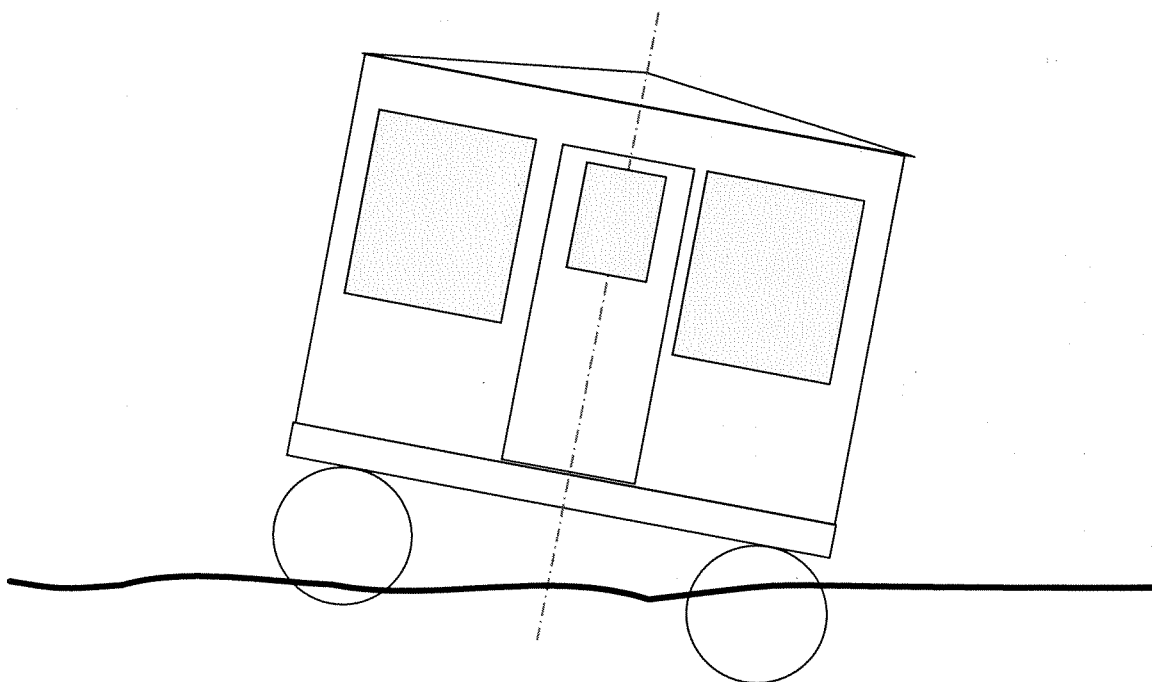
Figure 9 Residual Righting Arm for LADY D in a 40-Knot Wind

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Figure 10 Sketch of LADY D in the Heeled Condition

DELIVERABLE 3
TABLE OF WIND HEEL VERSUS RIGHTING ENERGY
FOR THREE LOADING CONDITIONS
FOR MV LADY D

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4300 King Street, Suite 400
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Loading Case	Total Load - pounds	Residual Righting Energy at Different Wind Speeds – foot-degrees		
		30 Knots	40 Knots	50 Knots
14 people at 140 lbs each	1960	37.32	27.79	16.70
25 people at 140 lbs each	3500	16.95	10.27	3.68
Actual Condition	4210	6.27	2.40	None

In the actual loading condition at a 50 knot wind speed, the vessel would capsize as the heeling energy is greater than the righting energy.